ANNEX 7 Uncertainty

The current U.S. Inventory reflects the best point estimates for emission and removal source categories relevant to the United States. These estimates were generated according to the UNFCCC reporting guidelines, following the recommendation in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Some of the current inventory estimates, such as those for CO_2 Emissions from Fossil Fuel Combustion and cement processing, are considered to be highly accurate and the extent of uncertainty associated with them is minimal. Other categories of emissions exist, however, for which the inventory emission estimates are considered to be less certain due to a lack of appropriate data and/or use of approximate estimation methodologies, resulting from a lack of complete information about the emission or removal process. As new information becomes available in the future, emission and sink estimates will continue to be improved and revised.

Estimation uncertainty (which refers to uncertainty arising from developing estimates and is the principal type and source of uncertainty associated with the national inventory estimates) comprises both model and parameter uncertainty. Model uncertainty refers to the uncertainty associated with developing mathematical equations or models to characterize the emission and/or removal processes. Model uncertainty can be evaluated by comparing the model results with the results of other models that are developed to characterize the same emission (removal) process and through sensitivity analysis. Since often only a single model has been developed to estimate emissions for any one source, it would be very difficult, if not impossible, to quantify the model uncertainty associated with the inventory estimates; therefore model uncertainty has not been estimated. Parameter uncertainty, on the other hand, refers to the uncertainty associated with inputs (e.g., activity data and emission factors) to the inventory estimation models; parameter uncertainty has been quantified for many emission sources in the Inventory.

7.1. Methodology

The United States has developed a quality assurance/quality control and uncertainty management plan in accordance with the IPCC Good Practice Guidance. Although this plan provides both general and specific guidelines for implementing quantitative uncertainty analysis, its components are intended to evolve over time, consistent with the inventory estimation process. The U.S. plan includes procedures and guidelines, and forms and templates, for developing quantitative assessments of uncertainty in the national Inventory estimates.

The IPCC Good Practice Guidance recommends two approaches—Tier 1 and Tier 2—for developing quantitative estimates of uncertainty in the inventory estimate of individual source categories and the overall inventory. In the case of the Tier 1 method, uncertainty estimates are developed through the error propagation equation, by combining the uncertainty associated with the activity data and the emission factors. However, if the uncertainties in input variables are large, the distributions underlying the input variables are not normal, and/or the uncertainties have significant covariance, adoption of the Tier 2 method is the recommended approach, as the Tier 1 approach to estimate uncertainties will not be appropriate under these circumstances. In the case of the Tier 2 method, which employs the Monte Carlo Stochastic Simulation technique, (1) values for emission factors and activity data are generated from their individual probability density functions, assigned as inputs to the analysis, and (2) the corresponding emission values are calculated by applying the mathematical equation specified for estimating emissions using the activity data and the emission factor(s).

The U.S. is in the process of implementing a multi-year strategy to develop quantiative estimates of uncertainty for all source categories. Over time, the United States hopes to implement a Tier 2 uncertainty analysis for all sources. As the current year was the first year of this three to five year process, where possible, a Tier 2 approach to the uncertainty analysis was implemented. For those sources where a Tier 2 approach was not feasible this year, a Tier 1 approach was implemented. For less than a dozen source categories, a Tier 1 approach was adopted, as shown in Table 7-1. The Tier 2 approach was implemented for several source categories, as permitted by data and resource availability, as contained in Table 7-2.

Quantative uncertainty estimates were not calculated for the following sources:

- Municipal Solid Waste Combustion (IPCC Source Category 1A5) N_2O;

- Natural Gas Flaring (IPCC Source Category 1B2) CO_2;
- Silicon Carbide Production (IPCC Source Category 2B4) CH_4;
- Bunker Fuels;*
- Biomass;* and
- Ambient Air Pollutants*

*Emissions and sinks from these sources are not included in total emissions.

Table 7-1: Uncertatinty estimates developed using Tier 1 uncertainty analysis

IPCC Source Category	Gas	Base Year Emissions[a]	Year 2002 emissions	Tier 1 Uncertainty of Source in 2002	2002 Uncertainty Range Relative to Emission Estimate		% change in emissions between 2002 and base year	Range of likely % change between year 2002 and base year		Key source?
		(Tg CO_2 Eq.)	(Tg CO_2 Eq.)	(%)	(Tg CO_2 Eq.)		(%)			
					Lower Bound	Upper Bound		Lower Bound	Upper Bound	
INDUSTRIAL PROCESSES										
Aluminum Production (IPCC Source Category 2C3)	CF_4	10.5	4.5	12%	4.0	5.1	-57%	-62%	-52%	✓
Aluminum Production (IPCC Source Category 2C3)	C_2F_6	1.3	0.7	19%	0.6	0.8	-48%	-58%	-38%	✓
Nitric Acid Production (IPCC Source Category 2B2)	N_2O	17.8	16.7	17%	13.9	19.6	-6%	-22%	10%	
Adipic Acid Production (IPCC Source Category 2B3)	N_2O	15.2	5.9	10%	5.3	6.5	-61%	-65%	-57%	✓
HCFC-22 Production (IPCC Source Category 2E1)	HFC-23	27.0	19.8	10%	17.8	21.8	-27%	-34%	-19%	✓
Electrical Transmission and Distribution (IPCC Source Category 2F7)	SF_6	21.7	14.8	13%	12.8	16.7	-32%	-41%	-23%	✓
Semiconductor Manufacture (IPCC Source Category 2F6)	HFC, PFC, and SF_6	5.0	4.4	10%	3.9	4.8	-12%	-21%	-3%	
Magnesium Production and Processing (IPCC Source Category 2C4)	SF_6	5.6	2.4	16%	2.0	2.8	-57%	-64%	-50%	
SOLVENT AND OTHER PRODUCT USE										
Nitrous Oxide Product Usage (IPCC Source Category 3D)	N_2O	4.3	4.8	7%	4.4	5.1	11%	3%	19%	
AGRICULTURE										
Field Burning of Agricultural Residues (IPCC Source Category 4F)	CH_4	0.7	0.7	70%	0.2	1.2	2%	-69%	74%	
Field Burning of Agricultural Residues (IPCC Source Category 4F)	N_2O	0.4	0.4	73%	0.1	0.7	15%	-69%	99%	
LAND-USE CHANGE AND FORESTRY (SINK)										
Changes in Carbon Stocks in Urban Trees (IPCC Source Category 5A5)	CO_2	(58.7)	(58.7)	39%	-81.4	-35.9	0%	39%	-39%	
WASTE										
Wastewater Treatment (IPCC Source Category 6B)	CH_4	24.1	28.7	39%	17.5	39.8	19%	-27%	65%	✓
Human Sewage (Domestic Wastewater) (IPCC Source Category 6B2)	N_2O	12.8	15.6	84%	2.5	28.6	22%	-81%	124%	

[a]1990 is the base year for sources of CO_2, CH_4, and N_2O. The base year for sources of HFCs, CFCs, and SF_6 is 1995.

Table 7-2: Uncertatinty estimates developed using Tier 2 uncertainty analysis

IPCC Source Category	Gas	Base Year Emissions[a]	Emissions (2002)	Uncertainty year 2002 emissions as % of emissions in the	% change in emissions	Range of likely % change between 2002 and base year	Key source?

						category	between 2002 and base year			
		(Tg CO_2 Eq.)	(Tg CO_2 Eq.)	% below (2.5 percentile)	% above (97.5 percentile)	(%)	Lower % (2.5 percentile)	Upper % (97.5% percentile)	
ENERGY									
Carbon Dioxide Emissions from Fossil Fuel Combustion (portion of IPCC Source Category 1A)	CO_2	4,814.7	5,611.0	-1%	5%	17%	15%	23%	✓
Stationary Combustion (excluding CO2) (portion of IPCC Source Category 1A)	CH_4	8.2	6.9	-38%	70%	-16%	-48%	42%	
Stationary Combustion (excluding CO2) (portion of IPCC Source Category 1A)	N_2O	12.6	14.0	-26%	181%	11%	-18%	211%	
Mobile Combustion (excluding CO2)	CH_4	5.0	4.2	-9%	9%	-15%	-23%	-7%	
Mobile Combustion (excluding CO2)	N_2O	50.7	52.9	-18%	17%	4%	-15%	22%	✓
Coal Mining (IPCC Source Category 1B1a)	CH_4	81.9	52.2	-15%	15%	-36%	-46%	-27%	✓
Abandoned Underground Coal Mines (IPCC Source Category 1B1a)	CH_4	3.4	4.1	-15%	17%	21%	3%	42%	
Petroleum Systems (IPCC Source Category 1B2a)	CH_4	28.9	23.2	-13%	41%	-20%	-30%	13%	✓
Natural Gas Systems (IPCC Source Category 1B2b)	CH_4	122.0	121.8	-40%	40%	0%	-40%	40%	✓
Municipal Solid Waste Combustion (IPCC Source Category 1A5)	CO_2	10.9	18.8	-17%	17%	72%	43%	102%	✓
INDUSTRIAL PROCESSES									
Iron and Steel Production (IPCC Source Category 2C1)	CO_2	85.4	54.4	-58%	78%	-36%	-73%	14%	✓
Iron and Steel Production (IPCC Source Category 2C1)	CH_4	1.3	1.0	-39%	39%	-25%	-54%	5%	
Cement Manufacture (IPCC Source Category 2A1)	CO_2	33.3	42.9	-13%	13%	29%	12%	46%	✓
Ammonia Manufacture (IPCC Source Category 2B1)	CO_2	12.6	9.6	-17%	17%	-23%	-36%	-10%	
Urea Application (IPCC Source Category 2B1)	CO_2	6.8	8.0	-8%	8%	19%	9%	28%	
Lime Manufacture (IPCC Source Category 2A2)	CO_2	11.2	12.3	-9%	8%	9%	0%	19%	
Limestone and Dolomite Use (IPCC Source Category 2A3)	CO_2	5.5	5.8	-17%	18%	5%	-12%	25%	
Soda Ash Manufacture and Consumption (IPCC Source Category 2A4)	CO_2	4.1	4.1	-7%	7%	0%	-7%	7%	
Titanium Dioxide Production (IPCC Source Category 2B5)	CO_2	1.3	2.0	-21%	21%	53%	21%	84%	
Phosphoric Acid Production (IPCC Source Category 2A7)	CO_2	1.5	1.3	-26%	28%	-12%	-35%	12%	
Ferroalloy Production (IPCC Source Category 2C2)	CO_2	2.0	1.2	-9%	9%	-38%	-43%	-32%	
Carbon Dioxide Consumption (IPCC Source Category 2B5)	CO_2	0.9	1.3	-10%	10%	43%	29%	56%	
Petrochemical Production (IPCC Source Category 2B5)	CH_4	1.2	1.5	-7%	8%	30%	21%	40%	
Substitution of Ozone Depleting Substances (IPCC Source Category 2F)	HFCs and PFCs	24.3	91.7	-1%	27%	278%	274%	380%	✓
Aluminum Production (IPCC Source Category 2C3)	CO_2	6.3	4.2	-23%	21%	-33%	-49%	-19%	
AGRICULTURE									

Enteric Fermentation (IPCC Source Category 4A)	CH_4	117.9	114.4	-11%	18%	-3%	-14%	15%	✓
Manure Management (IPCC Source Category 4B)	CH_4	31.0	39.5	-18%	20%	27%	4%	53%	✓
Manure Management (IPCC Source Category 4B)	N_2O	16.2	17.8	-16%	24%	10%	-7%	37%	
Rice Cultivation (IPCC Source Category 4C)	CH_4	7.1	6.8	-58%	116%	-4%	-60%	107%	
Agricultural Soil Management (IPCC Source Category 4D)	N_2O	262.8	287.3	-65%	156%	9%	-62%	180%	✓
LAND USE CHANGE AND FORESTRY									
Agricultural Soil Carbon Stocks (IPCC Source Category 5D)-Mineral Soils	CO_2	NA	(40.8) [b]	-42%	45%	NA	NA	NA	
Agricultural Soil Carbon Stocks (IPCC Source Category 5D)-Organic Soils	CO_2	NA	34.7[b]	-32%	-42%	NA	NA	NA	
WASTE									
Landfills (IPCC Source Category 6A1)	CH_4	210.0	193.0	-30%	30%	-8%	-36%	20%	✓

NA (Not Available)

[a] 1990 is the base year for sources of CO_2, CH_4, and N_2O. The base year for sources of HFCs, CFCs, and SF_6 is 1995.

[b] Includes mineral or organic soils only; estimates do not include the change in carbon storage resulting from the annual application of manure and sewage sludge, or the change in Conservation Reserve Program enrollment after 1997; the 2002 value represents the average of years 1993-2002.

7.2. Uncertainty Estimation as a Process

The IPCC Good Practice Guidance suggests that the resources expended for characterizing uncertainty in an inventory input should be proportional to its importance to the overall uncertainty assessment of the inventory. Therefore, to identify those input variables to which the overall uncertainty in the inventory is highly sensitive, IPCC recommends an iterative approach, wherein, in the first iteration of an uncertainty analysis, initial assessments of the uncertainty of input variables are made and propagated through the inventory in order to preliminarily identify the main sources of uncertainty (in terms of key input variables); subsequently, uncertainty in the key input variables are characterized more accurately through detailed investigations.

Identifying the sources of uncertainties in the emission and sink estimates of the Inventory and quantifying the magnitude of the associated uncertainty is the crucial first step towards improving those estimates. Quantitative assessment of the parameter uncertainties may also provide information about the relative importance of input parameters (such as activity data and emission factors), based on their relative contribution to the uncertainties within the source category estimates. Such information can be used to prioritize resources with a goal of reducing uncertainties over time within or among inventory source categories and their input parameters. In the current Inventory, potential sources of model uncertainty have been identified for some emission sources, and preliminary parameter uncertainty estimates have been developed for the vast majority of emission source categories.

Thus, a multi-year, multi-stage approach to the quantitative assessment of uncertainty of the U.S. Inventory was employed, which begins with the current year's preliminary assessment for identifying the key sources of uncertainty in the Inventory. Under this approach, quantitative estimates of uncertainty associated with the overall inventory will be conducted in stages, over a period of three to five years, such that at the end of this period, a credible uncertainty assessment for individual source categories and the overall inventory can be developed using the IPCC Tier 2 approach.

7.3. Planned Improvements

In this report, to estimate emissions and removals from the inventory source categories, IPCC methodologies (provided in the Revised 1996 IPCC Guidelines) were applied where appropriate, and were supplemented with other country-specific methodologies and data. In future inventory reports, additional efforts will be necessary to improve estimation methodologies and data collection procedures, thereby reducing uncertainty. Specific areas that require further research include:

- Incorporating excluded emission sources. Quantitative estimates of some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and industrial processes are not included either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex 5 for a discussion of the major sources of greenhouse gas emissions and sinks excluded from this report.

- Improving the accuracy of emission factors. Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to CH_4 and N_2O emissions from stationary and mobile combustion is highly uncertain.

- Collecting detailed activity data. Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of SF_6 from electrical transmission and distribution is limited due to a lack of activity data regarding national SF_6 consumption or average equipment leak rates.

The approach to uncertainty analysis employed in this Inventory recognizes that developing quantitative assessments of uncertainty is not an end in itself, but a crucial step toward improving inventory estimates through systematic analysis and identification of various sources of uncertainty in the inventory estimates. Further, since the reliability of quantitative assessment of uncertainty in the overall Inventory depends upon the accuracy of the uncertainty in the input data, the U.S. plan underscores the importance of developing credible quantitative uncertainty data for the activity- and emission factor-related inventory variables that underlie the emission estimates. This will require extensive use of expert elicitation to obtain the experts' quantitative judgments of uncertainty in the inventory input variables, as many of the inventory estimates for the input variables are point estimates and, often, statistical estimates of uncertainty in these estimates are not available. The United States proposes to combine detailed expert elicitation with less formal interviews (based on resource availability) to increase the availability of uncertainty data for the inventory input variables, and ultimately, allow an overall level of uncertainty for the Inventory to be estimated.